(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 981 222 A2

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
23.02.2000 Bulletin 2000/08

(51) Int Cl.7: H04L 5/06, H04M 11/06

(21) Application number: 99306377.5

(22) Date of filing: 12.08.1999

(84) Designated Contracting States:
AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE
Designated Extension States:
AL LT LV MK RO SI

(30) Priority: 19.08.1998 US 136721

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(54) Destination dependent coding for discrete multi-tone modulation

(57) Systems, methods and computer program products are provided for simultaneously transmitting data over a plurality of subscriber lines, such as twisted pair telephone wires, extending between a shared device and a respective plurality of remote devices using a symbol-based discrete multi-tone transmission scheme. A destination code within a first group of frequency bands and modulated data within a second group of frequency bands different from the first group of frequency bands, are transmitted from the shared device to the remote devices. The second group of frequency bands is selected for a subscriber line connected to a remote device having the destination code within the first group of frequency bands. A number of bits transmitted within each of the frequency bands in the second group of frequency bands for a remote device is selected during a communication handshake between the remote device and the shared device by probing a subscriber line connected to the remote device to determine data rates that can be supported by the subscriber line at each of a plurality of frequency bands.

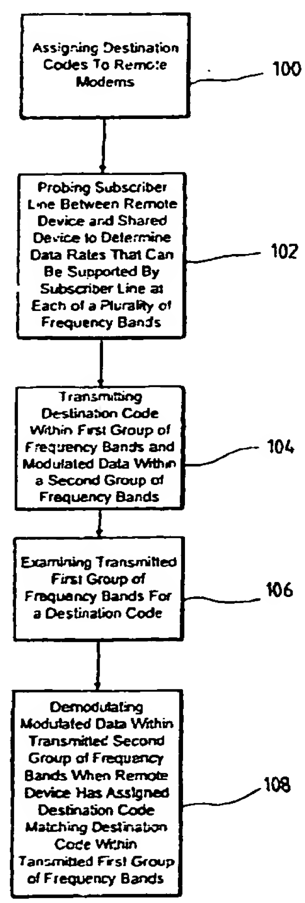

FIG. 5

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Description

Field of the Invention

[0001] The present invention relates generally to communications systems and, more particularly, to discrete multi-tone communications systems and digital subscriber line communications systems.

Background of the Invention

[0002] Remote client personal computers (PCs) are typically connected to the Internet over a telephone network of twisted-pair transmission lines via analog modems, as illustrated in **Fig. 1**. Unfortunately, analog modem speeds are currently limited to 56 thousand bits per second (56 Kbps) because of various constraints of existing telephone networks.

[0003] Asymmetrical Digital Subscriber Line (ADSL) technology is currently being developed to extend bandwidth over twisted-pair transmission lines by an order of magnitude. ADSL is based on a discrete multi- tone (DMT) transmission system. ADSL transmission rates over twisted pair transmission lines can reach as high as 8 million bits per second (8 Mbps) downstream (i.e., towards a client PC) and up to 256 Kbps upstream (towards a server). Data transmission rates for ADSL are substantially higher in the downstream direction than in the upstream direction. The asymmetric nature of ADSL fits well with data delivery requirements of the Internet. More data is typically transmitted downstream to a client PC than upstream from a client PC to a server.

[0004] Unfortunately, a significant problem currently plaguing the implementation of ADSL is the bandwidth burden placed on a telephone network by ADSL as illustrated in **Fig. 2**. In **Fig. 2**, lines **20** correspond to individual analog lines, such as local subscriber loops or lines and plain old telephone system (POTS) connections to a telephone company central office (CO) switch. Lines **22** correspond to T-1 lines (*i.e.*, lines having bandwidth capabilities of 1.544 Mbps and capable of carrying 24 digitized voiceband connections). Lines **24** correspond to T-3 lines (*i.e.*, lines having bandwidth capabilities of 28 T-1 lines and that are time-division multiplexed).

[0005] Although 24 analog POTS connections can be handled by a single T-1 line, 24 ADSL connections utilize almost the entire bandwidth of a T-3 line. This bandwidth constraint is further complicated by the fact that many analog subscriber lines may not terminate at a CO switch. Analog subscriber lines may terminate in remote locations, such as a manhole or utility box in a neighborhood, where a subscriber line is digitized and then routed to a CO switch via a T-1 or T-3 line. Increasing bandwidth for these remote links may be costly and may complicate implementation of ADSL.

[0006] In addition, current ADSL implementations typically include a dedicated pair of ADSL modems for each subscriber line. This is in contrast to voice-band modems, where a server only utilizes dedicated modems for each active connection. Requiring a dedicated pair of ADSL modems for each subscriber line may add significantly to the cost of ADSL implementation by telephone service providers.

[0007] Various solutions have been proposed to alleviate bandwidth constraints and thereby facilitate implementation of ADSL technology. One solution involves statistical multiplexing at the remote site. Another solution proposes terminating multiple ADSL subscriber lines in a single shared modem using common parameters for each connection. This may simplify hardware requirements on the telephone network side of each ADSL subscriber line because each subscriber line may share a high-speed transmitter. A single shared modem eliminates the need for separate ADSL modems for respective ADSL subscriber lines.

[0008] Unfortunately, a limitation of a single shared ADSL modem is that modems on the other end of subscriber lines connected to the shared modem may need to receive the same signal. Accordingly, the bandwidth of the transmitted signal within each frequency band may need to be reduced to accommodate the subscriber line in the group with the lowest bandwidth within each of the frequency bands. Accordingly, the net bandwidth that can be exploited by a shared modem on the server end may be less than that of a single modem on the worst line.

[0009] Various ways of overcoming limitations with shared ADSL modems have been proposed. For example, U.S. Patent No. 5,557,612 to Bingham relates to a system for establishing communications between a central unit and a plurality of remote units wherein access requests include an identification of each remote unit. A particular subchannel is allocated to the remote units by the central unit in an ADSL application. Units requiring bandwidth already allocated to other clients may be denied service. U.S. Patent No. 5,608,725 to Grube et al. relates to establishing a communications system wherein a primary site is coupled to a plurality of secondary sites via low pass transmission paths. However, only a single secondary site may be active at a time. Furthermore, the primary site allocates carrier channels of the inbound and outbound low pass transmission paths.

Summary of the Invention

[0010] One aspect of the present invention is to facilitate the implementation of ADSL by including statistical multiplexing within an ADSL modem.

[0011] It is another aspect of the present invention to facilitate the implementation of ADSL without requiring a separate ADSL modem at each end of a subscriber loop.

[0012] The present invention helps to lower costs associated with ADSL implementation.

[0013] The present invention is preferably implement-

ed. by systems, methods and computer program products for simultaneously transmitting data over a plurality of subscriber lines (*e.g.*, twisted pair telephone wires) extending between a shared device and a respective plurality of remote devices using a symbol-based discrete multi-tone transmission scheme, wherein a unique destination code is assigned to each of the remote devices. A destination code may be assigned to each remote device statically or dynamically during a communication handshake between each remote device and the shared device. An exemplary shared device with which the present invention may be utilized is a shared access ADSL modem. Exemplary remote devices with which the present invention may be utilized are ADSL modems.

[0014] Operations may include training each connection over each subscriber line to provide subscriber line specific information for each subscriber line, and transmitting and receiving information over each subscriber line utilizing the corresponding subscriber line specific information.

[0015] During each symbol interval, a destination code within a first group of frequency bands and modulated data within a second group of frequency bands different from the first group of frequency bands are transmitted from the shared device, via the plurality of subscriber lines, to the remote devices.

[0016] The number of bits per frequency band for the first group of frequency bands is selected as being receivable by each of the remote devices. The number of bits per frequency band for the second group of frequency bands is selected to maximize data transmission bandwidth for a subscriber line connected to a remote device having the destination code within the first group of frequency bands. The number of bits per frequency band for the second group of frequency bands for a remote device may be selected during a communication handshake between a remote device and a shared device by probing a subscriber line connected to the remote device to determine data rates that can be supported by the subscriber line at each of a plurality of frequency bands.

[0017] Operations for transmitting and receiving information over each subscriber line may include equalizing a received signal from a subscriber line utilizing the subscriber line specific information to provide client specific equalization coefficients. Operations for transmitting and receiving information over each subscriber line may include detecting symbols in the frequency domain representation of a signal received from a subscriber line utilizing the subscriber line specific information to provide client specific frequency information which defines the range of symbols encoded for each frequency.

[0018] In addition, operations for transmitting and receiving information over each subscriber line may include encoding, decoding, interleaving, deinterleaving, scrambling and descrambling the symbols of a signal received from a subscriber line utilizing the subscriber line specific information. Also, operations for transmitting and receiving information over each subscriber line may include mapping symbols to be transmitted on a subscriber line utilizing the subscriber line specific information.

[0019] According to another aspect of the present invention, systems, methods and computer program products are provided for receiving, at a remote device, such as an ADSL modem, data transmitted over a subscriber line extending from a shared device using a symbol-based discrete multi-tone transmission scheme, wherein the remote device has a unique destination code assigned thereto. A destination code may be assigned to each remote device statically or dynamically during a communication handshake between each remote device and a shared device. At each remote device receiving the transmitted first and second groups of frequency bands, the transmitted first group of frequency bands is examined for a destination code therewithin. At a remote device having an assigned destination code that matches a destination code within the transmitted first group of frequency bands, modulated data within the transmitted second group of frequency bands is demodulated. The number of bits per frequency band for the second group of frequency bands for the remote device may be selected during a communication handshake between the remote device and a shared device by probing the subscriber line (*e.g.*, a twisted pair telephone wire) connected to the remote device to determine data rates that can be supported by the subscriber line at each of a plurality of frequency bands.

[0020] According to another aspect of the present invention, systems, methods and computer program products are provided for simultaneously transmitting data over a plurality of subscriber lines, such as twisted pair telephone wires, extending between a shared device and a respective plurality of remote devices using a symbol-based discrete multi-tone transmission scheme. According to the present invention, a destination code within a first group of frequency bands and modulated data within a second group of frequency bands different from the first group of frequency bands, are transmitted from the shared device to remote devices. The number of bits per frequency band for the second group of frequency bands is selected for a subscriber line connected to a remote device having the destination code within the first group of frequency bands. The number of bits per frequency band for the second group of frequency bands for a remote device is selected during a communication handshake between the remote device and the shared device by probing a subscriber line connected to the remote device to determine data rates that can be supported by the subscriber line at each of a plurality of frequency bands.

[0021] The use of different downstream frequency band allocations for each remote device permits optimum performance for each subscriber line even though a shared ADSL modem is utilized. Accordingly, the

present invention can overcome significant limitations in the throughput capabilities of shared ADSL modems. As a result, costs associated with ADSL implementation can be lowered because a separate ADSL modem is not required at each end of a subscriber line.

Brief Description of the Drawings

[0022] **Fig. 1** illustrates an exemplary conventional telephone network of twisted-pair transmission lines and analog modems.

[0023] **Fig. 2** schematically illustrates bandwidth burden imposed on a conventional telephone network by an ADSL implementation.

[0024] **Fig. 3** schematically illustrates a shared access ADSL modem having a single high-speed shared DSL transmitter configured to handle multiple subscriber lines.

[0025] **Fig. 4** schematically illustrates frequency bandwidth allocation for DMT modulation.

[0026] **Fig. 5** schematically illustrates operations for carrying out aspects of the present invention.

[0027] **Fig. 6** is a block diagram of a system including a multi-drop server modem connected to multiple remote client modems according to the present invention.

[0028] **Fig. 7** is a block diagram of a particular embodiment of a multi-drop server modem according to the present invention.

[0029] **Fig. 8** is a block diagram of a particular embodiment of a client modem according to the present invention.

Detailed Description of the Invention

[0030] The present invention now will be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like elements throughout.

ADSL

[0031] As is known to those skilled in this art, an ADSL communication system includes an ADSL transceiver on each end of a subscriber line. In general, the ADSL transceivers of a subscriber line communicate with each other to establish a spectral response of the subscriber line. Once spectral response information is exchanged, transmission of data typically begins. The sending ADSL transceiver converts data provided in digital format, such as from a video camera, or internet web site images into a sequence of DMT symbols and conveys the DMT symbols to the other ADSL transceiver over the subscriber line. Upon receiving a sequence of DMT symbols, the receiving ADSL transceiver recaptures and reroutes the digital data, for example, to a user via a display screen or monitor. Using ADSL technology, high bandwidth data can be delivered to client PCs from a server using existing twisted pair transmission lines. ADSL is described in detail in the American National Standards Institute Draft Standard for Telecommunications - Network and Installation Interfaces - Asymmetrical Digital Subscriber Line (ADSL) Interface - ANSI Document No. T1.413, which is incorporated herein by reference in its entirety.

Shared ADSL Modem

[0032] Referring to **Fig. 3**, a shared access ADSL modem **30** for use with the present invention is illustrated. The illustrated modem **30** has a single high-speed shared DSL transmitter **32** configured to handle multiple subscriber lines. The illustrated shared DSL transmitter **32** receives data from a network server connected by a high-speed communications line through a receiver circuit **34**. The shared DSL transmitter **32** provides typical modem transmitter functions including error recovery protocols, line coding, filtering, modulation, and the like. The shared DSL transmitter **32** is also configured to embed a unique identifier within each signal frame transmitted to a respective remote modem.

[0033] Each subscriber line typically requires its own line interface circuit **38**, which isolates the source of the transmit signal from the subscriber line itself in order to keep the POTS and received modem signals for each subscriber line isolated. This line interface circuit **38** also provides the mechanism traditionally included within ADSL modems to tap off the analog POTS telephone bandwidth for traditional telephony connections. Because each client PC **29** connected to the shared access ADSL modem **30** receives the same signal, each client PC ADSL modem examines the incoming signal to filter out packets destined for other client PCs. Such filtering may be accomplished by accepting only packets which have an identifier corresponding to a preassigned address for a particular client PC.

[0034] On the upstream side of each subscriber line is a receiver **36**, as illustrated. Each modem receiver **36** may be similar to a V.34, V.PCM modem, or ADSL modem receiver, except that the signal is converted from a high frequency pass band to a base band signal via a mixer in the line interface circuit **38** before processing by the modem.

Discrete Multi-Tone Data Transmission

[0035] Many current ADSL implementations utilize a modulation scheme known as DMT modulation. A generalized illustration of frequency bandwidth allocation for DMT modulation is schematically shown in **Fig. 4**. The low frequency range **40** is reserved for POTS trans-

missions. Frequency ranges higher than the POTS frequency range **40** are used for ADSL transmissions. In **Fig. 4**, these high frequency ranges are divided into a group of frequency bands **42** for upstream signals and multiple frequency bands **44** for downstream signals. DMT modulation is also applicable to systems requiring an echo canceller where upstream frequency bands and downstream frequency bands share a common frequency range. The present invention is equally applicable to systems utilizing an echo canceller.

[0036] According to the present invention, within the multiple frequency bands **44** for downstream signals, a shared ADSL modem uses various line probing techniques to determine for each frequency band what data rate can be supported. The transmitter then splits-up the signal among the supported frequency bands according to the ability of each frequency band to support data throughput.

[0037] The present invention adapts the use of the multiple downstream frequency bands **44** to achieve optimum performance within a system which shares a high-speed digital subscriber loop transmitter among multiple subscriber lines. A small number of the downstream frequency bands **44** are allocated as carriers for destination codes of downstream or remote modems. In the illustrated embodiment of **Fig. 4**, frequency bands **44a** and **44b** are allocated as destination code carriers. Preferably, frequency bands for use as destination code carriers are selected on the basis of consistent throughput capabilities.

[0038] An ADSL frame is an amount of data that fits into one Fast Fourier Transform (FFT). Each ADSL frame can have a different destination code. There are alternate ways of embedding a control channel, which carries this destination code. One way is to add a control channel to a time domain signal. Another way involves the use of bursts of frames all destined for the same client. In this case, a destination code only needs to be sent in the first frame of an initial burst.

[0039] According to the present invention, each of the client PC modems sharing a common server modem has a unique destination code, either assigned statically or negotiated at the beginning of a session, such as during a communications handshake. One or more destination codes may also be assigned for use during the initial phases of a connection when destination codes are negotiated. All client receivers will process the signal through a FFT. A receiver in each client PC modem examines a destination code within a carrier frequency band or bands during each symbol interval and processes data in other frequency bands **44** only if the destination code matches a preassigned destination code. According to the present invention, a particular client PC modem can ignore downstream frequency bands **44** containing data when a destination code does not match the assigned destination code of the particular client PC modem (*i.e.*, data destined for another client PC).

[0040] The present invention can allow each subscriber line to "tune" its supported frequency bands to optimize bandwidth of a specific copper line, because a destination code will identify a symbol interval as only being valid for a specific subscriber line. Preferably, the shared server ADSL modem tracks which downstream frequency bands **44** are usable for each client PC modem and dynamically adjusts a modulated transmit signal based on which client modem is the intended recipient of the data.

[0041] Referring now to **Fig. 5**, operations for carrying out aspects of the present invention are schematically illustrated. Each remote modem is assigned a unique destination code (Block **100**). The assignment of unique destination codes may be performed statically or dynamically during a communications handshake between each remote modem and the shared modem.

[0042] During a communications handshake between a remote modem and the shared modem, the subscriber line connected to the particular remote modem is probed to determine data rates that can be supported at various frequency bands (Block **102**). The shared modem then transmits modulated data to each respective remote modem using destination codes per Block **100** above to control the desired recipient using only frequency bands to which the addressed subscriber line has been "tuned". Accordingly, data is preferably transmitted to each remote modem at an optimum data rate for each remote modem, and not at a sub-optimum data rate.

[0043] During actual data transmission between a shared server ADSL modem and a plurality of remote ADSL client modems, in each ADSL frame interval, a destination code is transmitted in a first group of frequency bands and modulated data is transmitted in at least one second group of frequency bands, different from the first group of frequency bands (Block **104**). Each remote ADSL modem examines a transmitted first group of frequency bands to determine if the first group of frequency bands contains a destination code matching a preassigned destination code of the remote modem (Block **106**). If a matching destination code is found, data contained within the second group of frequency bands is demodulated by the remote ADSL modem for use by a respective client PC (Block **108**).

[0044] It will be understood that each block of the flowchart illustrations of **Fig. 5** and combinations of blocks in the flowchart illustrations of **Fig. 5**, can be implemented by computer program instructions. These program instructions may be provided to a processor to produce a machine, such that the instructions which execute on the processor create means for implementing the functions specified in the flowchart block or blocks. The computer program instructions may be executed by a processor to cause a series of operational steps to be performed by the processor to produce a computer implemented process such that the instructions which execute on the processor provide steps for implementing the functions specified in the flowchart block or blocks.

[0045] Accordingly, blocks of the flowchart illustra-

tions support combinations of means for performing the specified functions, combinations of steps for performing the specified functions and program instruction means for performing the specified functions. It will also be understood that each block of the flowchart illustrations, and combinations of blocks in the flowchart illustrations, can be implemented by special purpose hardware-based systems which perform the specified functions or steps, or combinations of special purpose hardware and computer instructions.

[0046] **Fig. 6** illustrates one embodiment of a multidrop server modem connected to multiple client modems according to the present invention. As seen in **Fig. 6**, multiple workstations **216** may use individual ADSL modems **214** to connect to individual analog front ends **212** of a shared ADSL server modem **210** via individual twisted pair local loops **218**. The shared ADSL modem **210** then communicates with the digital interface **200** which provides the information from the multiple local loops connected to the analog front ends **212** to another network or processor such as a digital telephone network or Internet Service Provider (ISP).

[0047] Because of the asymmetric nature of ADSL, a server function is essentially a mirror image of the corresponding client function. While the client has a high-speed receiver and a lower speed transmitter, the server transmitter matches the high speed of the client receiver, and has a lower speed receiver. As will be seen in the description to follow, the client modem requires only minor changes to be compatible with a multi-line server modem. The analog front end of the multi-line server modem is significantly more complex than a single line server modem as an analog front end **212** is provided for each local loop. The shared functions of the ADSL modem also utilize additional working storage to handle client-specific state variables and coefficients.

[0048] The analog front ends **212**, preferably include separate splitters for POTS connections and isolation buffers to prevent signals from one client from coupling into another line. Each analog front end **212** also preferably includes a dedicated analog receive filter. However, in alternative embodiments, the analog front end may include an analog multiplexer (Mux) to a common sample-hold circuit followed by a common Analog-to-Digital converter. Alternatively, multiple sample-hold circuits may be used with an analog Mux to a common Analog-to-Digital converter. A third alternative uses multiple Analog-to-Digital converters, with multiplexing accomplished in the digital domain.

[0049] Alternatively, the complexities of sharing the upstream bandwidth may be reduced by implementing a separate complete receiver for each client as shown in **Fig. 3**. Since the server receiver operates at 1/8 the sample rate of the transmitter, a server system with one transmitter and eight receivers would require less than 1/4 the processing required to handle the same 8 clients with individual ADSL modems. Furthermore, this can be done without affecting bandwidth back to the digital interface, since it simply compensates for the asymmetric bit rate of the modems. While this alternative may increase the cost of a fully shared server modem, it may be a reasonable alternative if real-time traffic (*i.e.* voice or video conferencing) is a significant requirement for the service. Furthermore, the same hardware could potentially adapt to either by using different microcode loads, allowing the service provider to tune the modem density according to the level of service required.

[0050] While the above discussion described the multi-drop modem as having 8 clients per server modem, the number of clients supported by one server modem will be determined by several factors, regardless of whether the receiver function is dedicated per client or shared across a number of clients. For example, the additional memory required per client and the bandwidth allocated to the control channel carrying addressing information to select a specific client may limit the number of clients which can be supported. However, the number of clients per shared modem may ultimately be limited by individual user s expectations for level of service (*i. e.* response time) which limits the number of clients. Since different service providers may have different ideas as to the level of service their customers expect, the number of clients per server modem is preferably flexible to allow customization for particular users.

[0051] **Fig. 7** illustrates a particular embodiment of a shared DSL server modem according to the present invention. As will be appreciated by those of skill in the art, the embodiment illustrated in **Fig. 7** may be modified as described above with respect to the division between local loop specific and shared components.

[0052] As seen in **Fig. 7**, the multi-drop ADSL modem according to one embodiment of the present invention includes a digital interface **200** which allows connectivity to any device capable of communicating over the digital interface **200**. The digital interface **200** is bidirectional in that it receives data from the receive section or sections of the modem or provides data to the transmitter portion of the modem.

[0053] The type of digital interface **200** is not dependent on whether the modem supports multiple clients. For example, the digital interface may be a high-speed parallel bus which supports Direct Memory Access (DMA) or Bus Master data transfers, such as the PCI bus. Such modems may be used in an installation with multiple slots for ADSL modems, one or more slots for upstream connections, and a slot (or backplane) containing a system control processor and memory. In such a system, the multi-line modem may reduce loading and simplified Bus Master arbitration (due to fewer devices requiring access) for a system which supports a given number of client modem connections. Alternatively, for installations where a small number of clients are geographically isolated, the multi-line modem may be able to utilize a serial interface directly to link to a remotely located concentrator, since multiple clients are inherently already statistically multiplexed.

[0054] In light of the above discussion, the present invention should not be limited to any particular digital interface. Any number of suitable bus schemes and interfaces known to those of skill in the art may be used with the present invention to allow communication between the multi-drop ADSL modem and other devices.

[0055] The digital interface provides information to a L2 Framing and CRC Generation function **220**. A single L2 Framing/CRC Generation function **220** can be shared among multiple connections, leading to an implementation which is essentially the same as required for a single line modem. Each L2 Frame will be processed completely and placed in a packet buffer **222** before starting the next frame. This avoids a requirement of saving and restoring client specific intermediate results. Supporting multiple connections may require more packet buffers than required for the single line case. As illustrated in **Fig. 7** separate buffers **222** per connection would be the upper limit required. However, depending on the mechanism used to control data flow through the physical layer, the number of packet buffers may be reduced significantly below that level. Packet buffering requirements may actually approach the requirements for a single line modem if the L2 frame (equal to 69 physical layer frames) is chosen as the smallest entity directed to a specific connection.

[0056] The packet buffers **222** provide packets of data to an encoder **224**. The encoder **224** scrambles, Reed-Solomon codes and interleaves the packets. Scrambling, Reed-Solomon Encoding, and Interleaving processes should be essentially the same as that required for a single line server modem, since each L2 frame could be processed completely before moving to the next. CRC generation should coordinate multiple packet buffers. Tone ordering is dependent on learned line characteristics, and thus id preferably done differently for each client connection. Thus, client specific variables **248** are stored and provided to the encoder **224**. However, the same routine may be used for each connection by providing the client specific (i.e. local loop specific) information to the encoder **224** for use by the routine.

[0057] After the encoder **224**, the resulting symbols are provided to the symbol buffers **226**. As with the packet buffers **222**, the upper limit for symbol buffers should be the total number of connections allowed, however fewer may be used.

[0058] The symbol buffers **226** provide the symbols to the symbol mapper **228**. Symbol Mapping and gain scaling are also dependent on learned line characteristics, and thus must be done differently for each client connection. As with encoding, conventional symbol mapping may be used, however, client specific variables are used for the mapping. A single routine may process multiple connections by accessing the client specific state variables **246**. The symbol mapper **228** uses the client specific information to map the symbols to the frequencies of the multi-tone transmission. Thus, each client may have specific symbol values for each frequency which would be reflected in the stored client specific (*i.e.* local loop specific) variables **246**.

[0059] The output of the symbol mapper **228** may then be provided to a 256 complex symbol buffer **230** which outputs the complex symbols to the Inverse Discrete Fourier Transform (IDFT) circuit **232**. The IDFT **232** of the present invention may be identical to that of a conventional ADSL modem. The IDFT **232** converts the complex frequency domain symbols to real time domain symbols in accordance with well-known Fourier Transform processes. The real symbols are provided to a 512 symbol buffer **234** which then provides them to the parallel to serial converter **236** which may insert the framing bit. The parallel to serial conversion and insertion of the framing bit and cyclic prefix may be identical to that of a conventional single line ADSL modem.

[0060] The parallel to serial converter provides the serial information to the Digital to Analog converter (D/A) **238** which converts the digital signal to an analog signal. The analog signal is provided to the transmit filter **240** which provides the filtered signal to an isolation buffer **242** for each local loop. The isolation buffers reduce the likelihood of each local loop interfering with other local loops. From the isolation buffer **242** the analog signal is provided to the local loop.

[0061] As will be appreciated by those of skill in the art, the present invention utilizes a client identifier or local loop identifier throughout the transmission processes described above. Thus, each of the functions, such as the encoder **224** and the symbol mapper **228** may utilize the identifier to select the client or local loop specific information to use in their processing. Such an identifier may take many forms, such as a header in the data or as a discrete signal decoded from information in the data received by the digital interface **200**. Accordingly, the present invention should not be construed as limited to any particular method of providing identification of the local loop associated with data to the various functions of the transmitter of the ADSL modem.

[0062] The receiver of **Fig. 7** receives signals from the local loops at isolation buffers **252**. The isolation buffers serve to isolate each local loop from the other. The isolation buffers **252** may provide the received signals to an analog multiplexer **254** which provides one of the signals to an analog to digital converter **256**. As described above, the demarcation between individual components and shared components may vary in different embodiments of the present invention. Thus, the present invention should not be construed as limited to the example of **Fig. 7**.

[0063] The analog to digital converter **256** may be a conventional analog to digital converter. The analog to digital converter **256** converts the received analog signal to a digital signal which is provided to the time domain equalizer **258**. A single time-domain equalizer may be used, however, the timing coefficients should be selected from multiple client-specific sets. The stored client specific variables **260** may be selected by the equal-

izer **258** based on the physical line selected by the multiplexer **254**. Alternatively, other selection methods may be used, as described with respect to the transmitter portion of the client modem.

[0064] The time domain equalizer **258** provides an equalized digital signal to both the Sync Search function **282** and the serial to parallel converter **262**. The sync search **282** and parallel to serial converter **262** may be the same as those used in conventional ADSL modems. However, the sync search function **282** may have to be disabled when switching from one client line to another, depending on how quickly switching transients settle out. Ideally, a new client could be transmitting immediately after switching the multiplexer, but at least one physical frame of dead time when switching may be required.

[0065] The serial to parallel converter **262** converts the serial digital signal to a parallel digital signal and provides the parallel signal to 64 real symbol buffers **264**. The real symbol buffers **264** provide the symbols to the Discrete Fourier Transformation (DFT) function **266** which converts the symbols from the time domain to the frequency domain and provides 32 complex symbols to the complex symbol buffers **268**. The DFT **266** may be the same as conventional DFT functions. The complex symbol buffers **268** then provide the symbols to the symbol detector **284**.

[0066] Like the time-domain equalization **258**, the frequency-domain equalization and symbol detection function **284** is dependent on the line characteristics learned for the specific client connection. Therefore, at each processing interval, a set of client specific coefficients and state variables, coordinated with the state of the front-end multiplexer **254**, must be used to process the symbols generated by the DFT **266**. Otherwise, the symbol detector **284** may function as a convention ADSL symbol detector. The client specific variables **280** may be stored and provided to the symbol detector **284**. The selection of the client specific variables **280** may be based on the multiplexer **254** or by other means, as described above.

[0067] The symbol detector **284** outputs the symbols to symbol buffers **270** which provide the symbols to the decoder **272**. As with the transmitter, the maximum number of symbol buffers **270** required is one for each local loop. The decoder **272** descrambles, Reed-Solomon decodes and de-interleaves the symbols. Descrambling, Reed-Solomon Decoding, and De-interleaving processes should be essentially the same as that required for a single line server modem, since each L2 frame could be processed completely before moving to the next. Some additional complexity may be required to coordinate multiple packet buffers. Tone ordering is dependent on learned line characteristics, and thus must be done differently for each client connection. Therefore, like the symbol detector **284**, the decoder **272** will access client specific variables **278** to perform its functions. The selection of the client specific variables **278** may be the same as that described above. A single routine may process multiple connections by accessing the client specific state variables **278**.

[0068] The decoder outputs packets to the packet buffers **274** which provide the packets to the L2 Framing/CRC check function **276**. A single L2 Framing/CRC Check function **276** can be shared among multiple connections. Thus, the L2 Framing/CRC Check function **276** may be essentially the same as required for a single line modem. Each L2 Frame will be processed completely from a packet buffer **274**, and placed in a DMA queue before starting the next frame. This avoids a requirement of saving and restoring client specific intermediate results. Supporting multiple connections may require more packet buffers than required for the single line case. **Fig. 7** shows separate buffers per connection as an upper limit, but, depending on the mechanism used to control data flow through the physical layer, the number of packet buffers may be reduced significantly below that level. The L2 framing/CRC Check function **276** then provides the packets to the digital interface **200** for transmission.

[0069] **Fig. 8** illustrates a particular embodiment of a client modem according to the present invention. As seen in **Fig. 8**, the client ADSL modem according to one embodiment of the present invention includes a digital interface **300** which allows connectivity to any device capable of communicating over the digital interface **300**. The digital interface **300** is bidirectional in that it receives data from the receive section of the modem or provides data to the transmitter portion of the modem. The digital interface **300** may be a conventional digital interface for ADSL modems.

[0070] The digital interface **300** provides information to a L2 Framing and CRC Generation function **320**. The L2 Framing and CRC generation function **320** may be the same as used in conventional ADSL modems. Each L2 Frame will be processed and placed in a packet buffer **322**.

[0071] The packet buffer **322** provides packets of data to an encoder **324**. The encoder **324** scrambles, Reed-Solomon codes and interleaves the packets. Scrambling, Reed-Solomon Encoding, and Interleaving processes should be essentially the same as that required for a conventional single line modem. Tone ordering is dependent on learned line characteristics and utilizes the state variables **348** which are stored and provided to the encoder **324**.

[0072] After the encoder **324**, the resulting symbols are provided to the symbol buffer **326**. The symbol buffer **326** provides the symbols to the symbol mapper **328**. Symbol mapping and gain scaling are also dependent on learned line characteristics using the state variables **346**. The symbol mapper **328** uses the state variables **346** to map the symbols to the frequencies of the multitone transmission. The symbol mapper **328** may also receive information from the upstream access arbitration function **400** to be utilized in the arbitration for band-

width between multiple clients and the shared ADSL modem. Thus, the symbol mapper **328** may be a conventional symbol mapper with the addition of provisions for the particular arbitration or bandwidth allocation scheme employed by the shared ADSL modem. Various such schemes are described below.

[0073] The output of the symbol mapper **328** may then be provided to a 32 complex symbol buffer **330** which outputs the complex symbols to the Inverse Discrete Fourier Transform (IDFT) circuit **332**. The IDFT **332** of the present invention may be identical to that of a conventional ADSL modem. The IDFT **332** converts the complex symbols to real symbols by converting from the frequency domain to the time domain. The real symbols are provided to a 64 symbol buffer **334** which then provides them to the parallel to serial converter **336** which may insert the framing bit and cyclic prefix. The parallel to serial conversion and insertion of the framing bit and cyclic prefix may be identical to that of a conventional single line ADSL modem.

[0074] The parallel to serial converter **336** provides the serial information to the Digital to Analog converter (D/A) **338** which converts the digital signal to an analog signal. The analog signal is provided to the transmit filter **340** which provides the filtered signal to the local loop.

[0075] The receiver of **Fig. 8** receives signals from the local loop at receive filter **352**. The receive filter **352** provides the signal to an analog to digital converter **356**. The analog to digital converter **356** may be a conventional analog to digital converter. The analog to digital converter **356** converts the received analog signal to a digital signal which is provided to the time domain equalizer **358**. The time-domain equalizer uses stored equalization coefficients **360**. A conventional time domain equalizer may be utilized.

[0076] The time domain equalizer **358** provides an equalized digital signal to both the Sync Search function **382** and the serial to parallel converter **362**. The sync search **382** and serial to parallel converter **362** may be the same as those used in conventional ADSL modems.

[0077] The serial to parallel converter **362** converts the serial digital signal to a parallel digital signal and provides the parallel signal to 512 real symbol buffer **364**. The real symbol buffer **364** provides the symbols to the Discrete Fourier Transformation (DFT) function **366** which converts the symbols from the time domain to the frequency domain and provides 256 complex symbols to the complex symbol buffer **368**. The DFT **366** may be the same as conventional DFT functions. The complex symbol buffer **368** then provides the symbols to the symbol detector **384**.

[0078] Like the time-domain equalization **358**, the frequency-domain equalization and symbol detection function **384** is dependent on the line characteristics learned for the client connection. The symbol detector **384** utilizes the state variables **380** in detecting the symbols. The symbol detector **384** may function as a convention ADSL symbol detector however, the symbol detector also detects whether the message is directed to the specific client modem. Thus, the symbol detector **384** may examine the frequency band(s) allocated to the control channel function, to determine on a frame by frame basis if the set of physical symbols is addressed to that specific client. If not, those frames are discarded and further processing is not necessary during that interval. This process could alternately be done only once per superframe (69 frames), depending on the granularity of the multiplexing. The symbol detector **384** may also provide information to the upstream access arbitration function **400** for use in the arbitration scheme for allocating bandwidth.

[0079] If the symbols are for the client modem, the symbol detector **384** outputs the symbols to symbol buffer **370** which provides the symbols to the decoder **372**. The decoder **372** performs descrambling, Reed- Solomon decodeing and de-interleaving. The decoder **372** outputs packets to the packet buffer **374** which provide the packets to the L2 Framing/CRC check function **376**. The L2 framing/CRC Check function **376** then provides the packets to the digital interface **300** for transmission. The decoder **372** and L2 Framing/CRC check **376** functions may be the same as conventional client modems. Thus, the decoder **372** may use state variables **378** to perform its functions.

[0080] As with single line modems, timing must be synchronized between the transmitter D/A converter and the receiver A/D converter this function is performed by the timing and control function **250** of the server modem and timing and control function **350** in the client modem. The synchronization of the converters may be carried out by conventional timing and control functions. Additional control is required in the Multi- line Server to coordinate the sharing of upstream bandwidth. The server must know which client is enabled to transmit during each possible transmit frame, and coordinate the control of the analog multiplexer at the front end to select the active client. These functions are performed by the timing and control function **250** in the server modem and the upstream access arbitration function **400** in the client modem. A control protocol enables each client to request upstream bandwidth without interfering with current transmission, enables each client to quantify its bandwidth requirements, and enables the server to control which client modem will be allowed to transmit at each possible interval. Fixed allocations, either time multiplexed or frequency multiplexed may be simplest to implement, but would not make optimum use of available bandwidth. Asynchronous access with collision detection is another possibility, but a client may not be able to detect a collision with another client using a different local loop. This would force the server to determine client collisions and request retransmissions. A control message could be broadcast to all clients simultaneously to accomplish this.

[0081] In another control approach, bandwidth is separated via Time Division Multiplexing (TDM) between all

active clients. A protocol which allows each client to either give up some of the allocated bandwidth or request additional bandwidth on a dynamic basis could then be implemented. Alternatively, only a small percent of the bandwidth would be allocated to each client. This guarantees a periodic channel for communicating requests for additional bandwidth. Access to the bandwidth not allocated to any client can then be granted dynamically by the server based on pending requests.

[0082] Each of the above described control methods for allocating bandwidth between clients may be readily implemented by those of skill in the art. Furthermore, other types of control methods known to those of skill in the art may also be used while still benefitting from the teachings of the present invention. Accordingly, the present invention should not be construed as limited to any particular method of allocating bandwidth to clients.

[0083] As is clear from the above discussion, the shared ADSL modem of the present invention allows for multiple connections by isolating the local loops and then using local loop dependent information to communicate with the local loops. This local loop dependent information may be stored in various memory devices, registers, latches or other storage devices known to those of skill in the art. Furthermore, as will be appreciated by those of skill in the art, the local loop dependent information may be stored in a central storage area or in individual storage areas associated with each modem function. Accordingly, the present invention should not be limited to any particular storage configuration.

[0084] The foregoing is illustrative of the present invention and is not to be construed as limiting thereof. Although a few exemplary embodiments of this invention have been described, those skilled in the art will readily appreciate that many modifications are possible in the exemplary embodiments without materially departing from the novel teachings and advantages of this invention. Accordingly, all such modifications are intended to be included within the scope of this invention. Therefore, it is to be understood that the foregoing is illustrative of the present invention and is not to be construed as limited to the specific embodiments disclosed, and that modifications to the disclosed embodiments, as well as other embodiments, are intended to be included within the scope of the invention.

[0085] According to one aspect of the invention, there is provided a method of receiving, at a remote device, data transmitted over a subscriber line extending from a shared device using a symbol-based discrete multitone transmission scheme, wherein the remote device has a unique destination code assigned thereto, the method comprising the steps of: receiving transmitted first and second groups of frequency bands using a symbol-based discrete multi- tone transmission scheme; examining the transmitted first group of frequency bands using a symbol-based discrete multi- tone transmission scheme for a destination code therewithin; and demodulating modulated data within the second group of frequency bands using a symbol-based discrete multi-tone transmission scheme when a destination code transmitted within the first group of frequency bands matches a destination code assigned to the remote device.

[0086] A destination code may be assigned to the remote device statically. Alternatively, a destination code is assigned to the remote device dynamically during a communication handshake between the remote device and the shared device.

[0087] Preferably, a number of bits transmitted within each of the frequency bands in the second group of frequency bands for the remote device is selected during a communication handshake between the remote device and the shared device by probing the subscriber line connected to the remote device to determine data rates that can be supported by the subscriber line at each of a plurality of frequency bands.

[0088] The shared device is preferably a shared access ADSL modem. Each of the remote devices is preferably also an ADSL modem. Each subscriber line is preferably a twisted pair telephone wire.

[0089] In another aspect, the invention provides a method of simultaneously transmitting data over a plurality of subscriber lines extending between a shared device and a respective plurality of remote devices using a symbol-based discrete multi-tone transmission scheme, wherein each of the remote devices has a unique destination code assigned thereto, the method comprising the steps of: during each symbol interval, transmitting from the shared device, via the plurality of subscriber lines, a destination code within a first group of frequency bands and modulated data within a second group of frequency bands different from the first group of frequency bands using a symbol-based discrete multi-tone transmission scheme, wherein the second group of frequency bands is selected for a subscriber line connected to a remote device having the destination code assigned thereto; at each remote device receiving the transmitted first and second groups of frequency bands using a symbol-based discrete multi-tone transmission scheme, examining the transmitted first group of frequency bands for a destination code therewithin; and at a remote device having an assigned destination code that matches a destination code within the transmitted first group of frequency bands, demodulating modulated data within the transmitted second group of frequency bands.

[0090] A destination code may be assigned to each remote device statically, or a destination code may be assigned to each remote device dynamically during a communication handshake between each remote device and the shared device.

[0091] A number of bits transmitted within each of the frequency bands in the second group of frequency bands for a remote device is preferably selected during a communication handshake between the remote device and the shared device by probing a subscriber line connected to the remote device to determine data rates

that can be supported by the subscriber line at each of a plurality of frequency bands.

[0092] The shared device is preferably a shared access ADSL modem. Each of the remote devices is preferably also an ADSL modem.

[0093] Preferably, the first group of frequency bands is selected as being receivable by each of the remote devices.

[0094] Preferably, each subscriber line is a twisted pair telephone wire.

[0095] In another aspect, there is provided a method of simultaneously transmitting data over a plurality of subscriber lines extending between a shared device and a respective plurality of remote devices using a symbol-based discrete multi-tone transmission scheme, the method comprising: transmitting to the shared device a destination code within a first group of frequency bands and modulated data within a second group of frequency bands different from the first group of frequency bands using a symbol-based discrete multi- tone transmission scheme, wherein the second group of frequency bands is selected for a subscriber line connected to a remote device having the destination code within the first group of frequency bands.

[0096] A destination code is preferably assigned to each remote device dynamically during a communication handshake between each remote device and the shared device.

[0097] The second group of frequency bands for a remote device is preferably selected during a communication handshake between the remote device and the shared device by probing a subscriber line connected to the remote device to determine data rates that can be supported by the subscriber line at each of a plurality of frequency bands.

[0098] The shared device is preferably a shared access ADSL modem and each of the remote devices is preferably also an ADSL modem. Preferably, each subscriber line is a twisted pair telephone wire.

[0099] In another aspect, the invention provides a computer program product for simultaneously transmitting data over a plurality of subscriber lines extending between a shared device and a respective plurality of remote devices using a symbol-based discrete multi-tone transmission scheme, wherein each of the remote devices has a unique destination code assigned thereto, the computer program product comprising a computer usable storage medium having computer readable program code means embodied in the medium, the computer readable program code means comprising: computer readable program code means for transmitting from the shared device, via the plurality of subscriber lines during each symbol interval, a destination code within a first group of frequency bands and modulated data within a second group of frequency bands different from the first group of frequency bands using a symbol-based discrete multi- tone transmission scheme, wherein bits transmitted in each of the frequency bands in the second group of frequency bands are selected for a subscriber line connected to a remote device having the destination code assigned thereto; at each remote device receiving the transmitted first and second group of frequency bands, computer readable program code means for examining the transmitted first group of frequency bands for a destination code therewithin; and at a remote device having an assigned destination code that matches a destination code within the transmitted first group of frequency bands, computer readable program code means for demodulating modulated data within the transmitted second group of frequency bands.

Claims

1. A method of simultaneously transmitting data over a plurality of subscriber lines extending between a shared device and a respective plurality of remote devices using a symbol-based discrete multi-tone transmission scheme, the method comprising:

   training each connection over each subscriber line extending between a shared device and a respective plurality of remote devices using a symbol-based discrete multi-tone transmission scheme to provide subscriber line specific information for each subscriber line; and

   transmitting and receiving information over each subscriber line extending between a shared device and a respective plurality of remote devices using a symbol-based discrete multi-tone transmission scheme utilizing the corresponding subscriber line specific information.

2. A method according to Claim 1, further comprising the step of assigning each of the remote devices a unique destination code.

3. A method according to Claim 1, further comprising the step of transmitting to each remote device a destination code within a first group of frequency bands and modulated data within a second group of frequency bands different from the first group of frequency bands, wherein bits transmitted in each of the frequency bands in the second group of frequency bands are selected for a subscriber line connected to a remote device having the destination code within the first group frequency band.

4. A method according to Claim 2 or claim 3 wherein a destination code is assigned to each remote device dynamically during a communication handshake between each remote device and the shared device.

5. A method according to Claim 3 wherein the second group of frequency bands for a remote device is selected during a communication handshake between the remote device and the shared device by probing a subscriber line connected to the remote device to determine data rates that can be supported by the subscriber line at each of a plurality of frequency bands.

6. A method according to any preceding claim wherein the shared device is a shared access ADSL modem and wherein each of the remote devices is an ADSL modem.

7. A method according to any preceding claim wherein the client specific information is obtained during a communication handshake between the remote device and the shared device by probing a subscriber line connected to the remote device to determine data rates that can be supported by the subscriber line at each of a plurality of frequency bands.

8. A method according to Claim 3 wherein each subscriber line is a twisted pair telephone wire.

9. A method according to any preceding claim, wherein the step of transmitting and receiving further comprises the step of equalizing a received signal from a subscriber line utilizing the subscriber line specific information to provide client specific equalization coefficients.

10. A method according to any preceding claim, wherein said step of transmitting and receiving further comprises the step of detecting symbols in the frequency domain representation of a signal received from a subscriber line utilizing the subscriber line specific information to provide client specific frequency information which defines the range of symbols encoded for each frequency.

11. A method according to any preceding claim, wherein said step of transmitting and receiving further comprises the steps of decoding, deinterleaving and descrambling the symbols of a signal received from a subscriber line utilizing the subscriber line specific information.

12. A method according to any preceding claim, wherein said step of transmitting and receiving further comprises the steps of encoding, interleaving and scrambling the symbols to be transmitted on a subscriber line utilizing the subscriber line specific information.

13. A method according to any preceding claim, wherein said step of transmitting and receiving further comprises the step of mapping symbols to be transmitted on a subscriber line utilizing the subscriber line specific information.

14. A method of receiving, at a remote device, data transmitted over a subscriber line extending from a shared device using a symbol-based discrete multitone transmission scheme, wherein the remote device has a unique destination code assigned thereto, the method comprising the steps of:

    receiving transmitted first and second groups of frequency bands using a symbol-based discrete multi- tone transmission scheme;

    examining the transmitted first group of frequency bands using a symbol-based discrete multi- tone transmission scheme for a destination code therewithin; and

    demodulating modulated data within the second group of frequency bands using a symbol-based discrete multi-tone transmission scheme when a destination code transmitted within the first group of frequency bands matches a destination code assigned to the remote device.

15. A system for simultaneously transmitting data over a plurality of subscriber lines extending between a shared device and a respective plurality of remote devices using a symbol-based discrete multi-tone transmission scheme, comprising:

    means for training each connection over each subscriber line extending between a shared device and a respective plurality of remote devices using a symbol- based discrete multi-tone transmission scheme to provide subscriber line specific information for each subscriber line; and

    means for transmitting and receiving information over each subscriber line extending between a shared device and a respective plurality of remote devices using a symbol-based discrete multi-tone transmission scheme utilizing the corresponding subscriber line specific information.

16. A computer program for controlling the operation of a data processing apparatus to simultaneously transmit data over a plurality of subscriber lines extending between a shared device and a respective plurality of remote devices using a symbol-based discrete multi-tone transmission scheme, the computer program comprising:

    computer readable program code for training each connection over each subscriber line ex-

tending between a shared device and a respective plurality of remote devices using a symbol-based discrete multi-tone transmission scheme to provide subscriber line specific information for each subscriber line; and

computer readable program code for transmitting and receiving information over each subscriber line extending between a shared device and a respective plurality of remote devices using a symbol- based discrete multi-tone transmission scheme utilizing the corresponding subscriber line specific information.

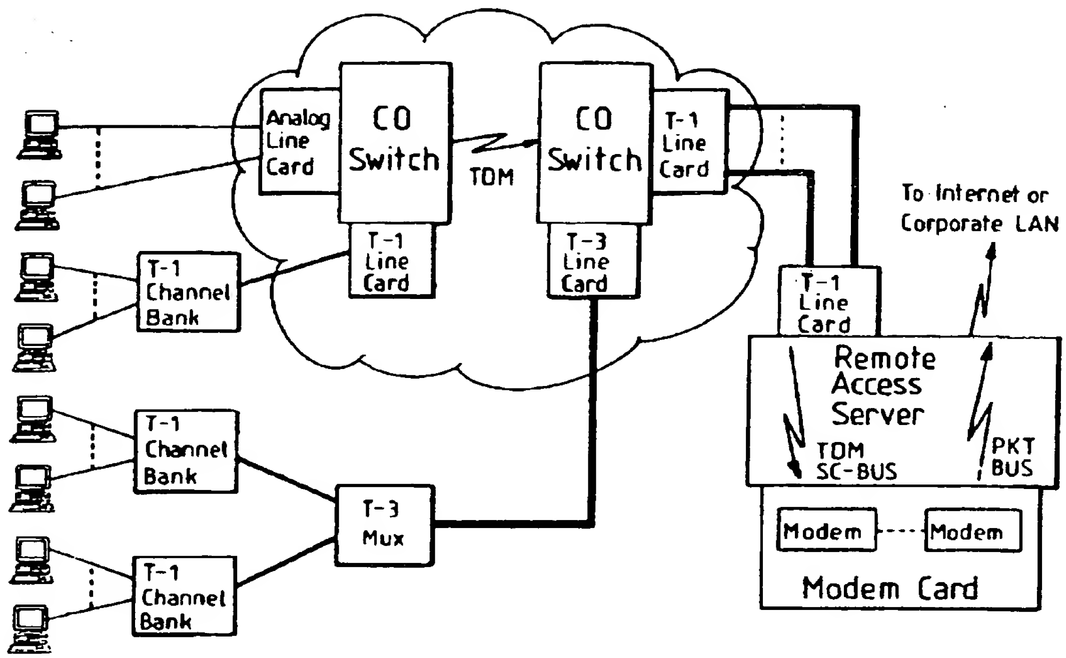
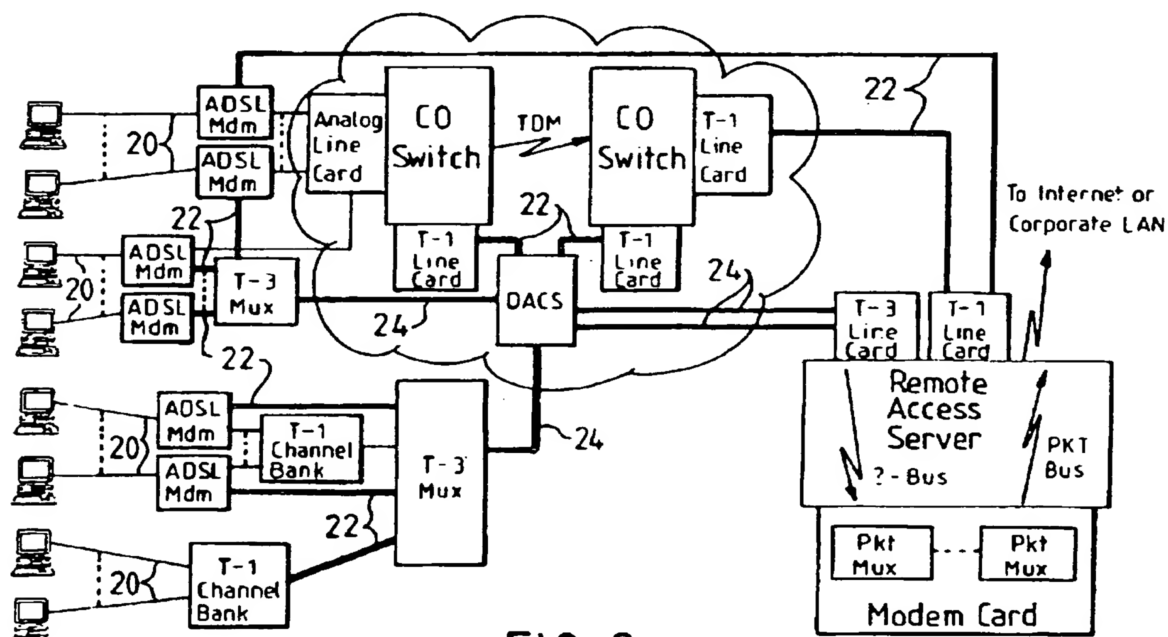

Analog
Line
Card
CO
Switch
TDM
CO
Switch
T-1
Line
Card
T-1
Line
Card
T-3
Line
Card
T-1
Channel
Bank
T-1
Channel
Bank
T-1
Channel
Bank
T-3
Mux
T-1
Line
Card
To Internet or
Corporate LAN
Remote
Access
Server
TDM
SC-BUS
PKT
BUS
Modem
Modem
Modem Card

FIG. 1


ADSL
Mdm
ADSL
Mdm
20
Analog
Line
Card
CO
Switch
TDM
CO
Switch
T-1
Line
Card
22
22
T-1
Line
Card
T-1
Line
Card
ADSL
Mdm
ADSL
Mdm
20
T-3
Mux
DACS
24
24
22
To Internet or
Corporate LAN
T-3
Line
Card
T-1
Line
Card
ADSL
Mdm
ADSL
Mdm
20
T-1
Channel
Bank
T-3
Mux
24
Remote
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Pkt
Mux
Pkt
Mux
Modem Card

FIG. 2

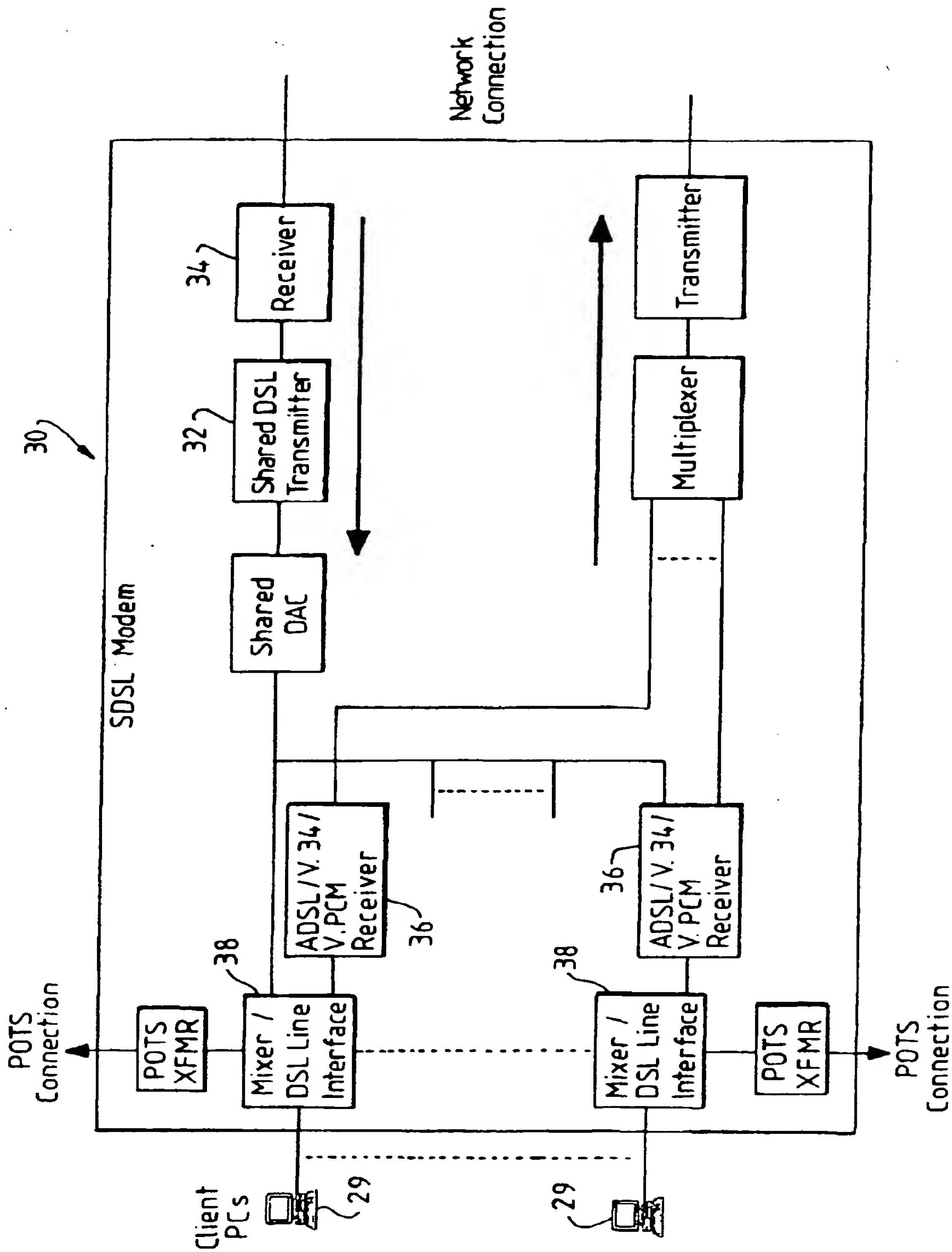

Network Connection
30
SDSL Modem
34
Receiver
32
Shared DSL Transmitter
Shared DAC
Transmitter
Multiplexer
ADSL/V.34/ V.PCM Receiver
36
36
ADSL/V.34/ V.PCM Receiver
38
38
Mixer / DSL Line Interface
Mixer / DSL Line Interface
POTS XFMR
POTS XFMR
POTS Connection
POTS Connection
Client PCs
29
29

FIG. 3

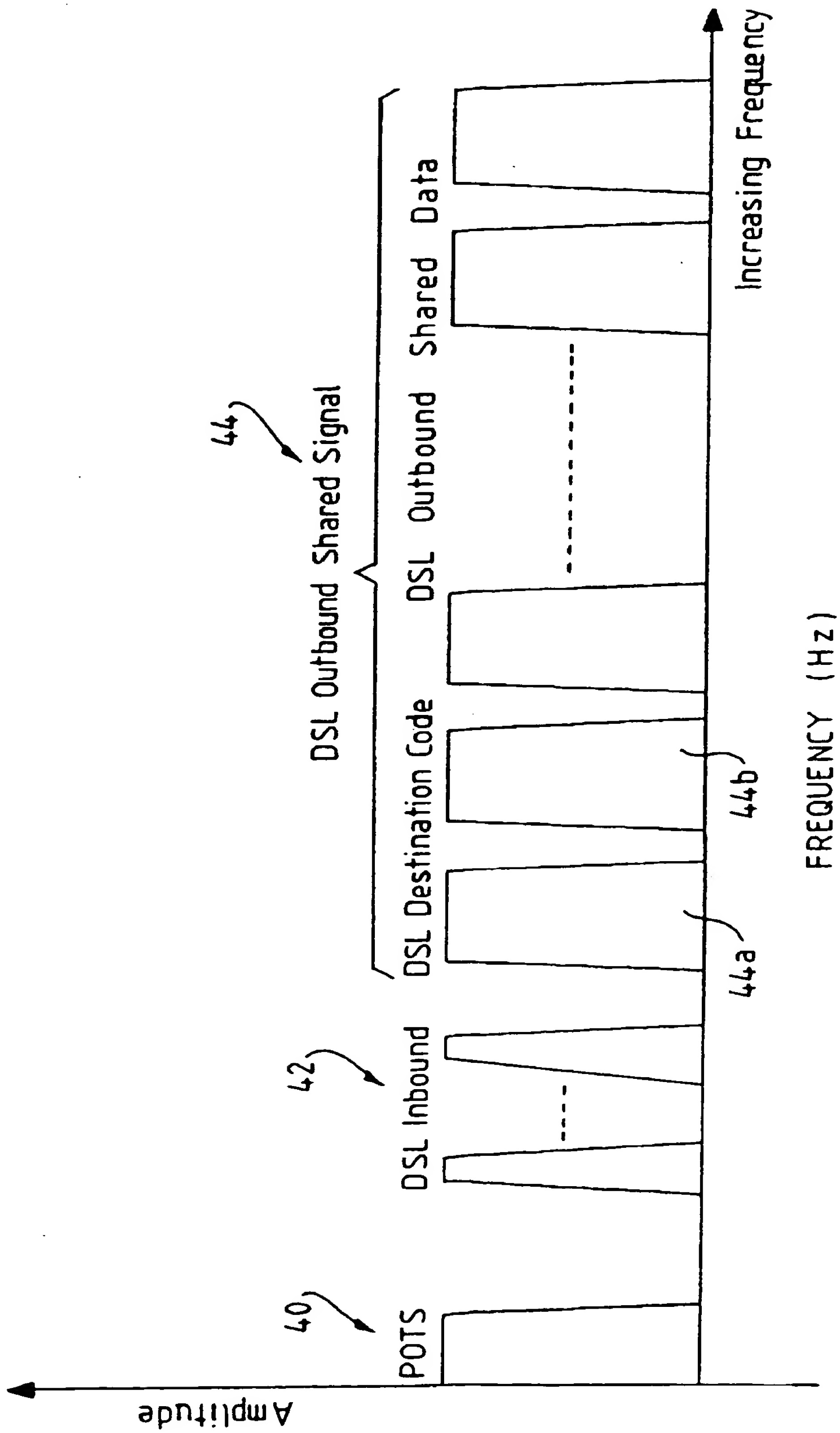

Amplitude
POTS
40
DSL Inbound
42
DSL Destination Code
44a
44b
DSL Outbound Shared Data
DSL Outbound Shared Signal
44
Increasing Frequency
FREQUENCY (Hz)

FIG. 4

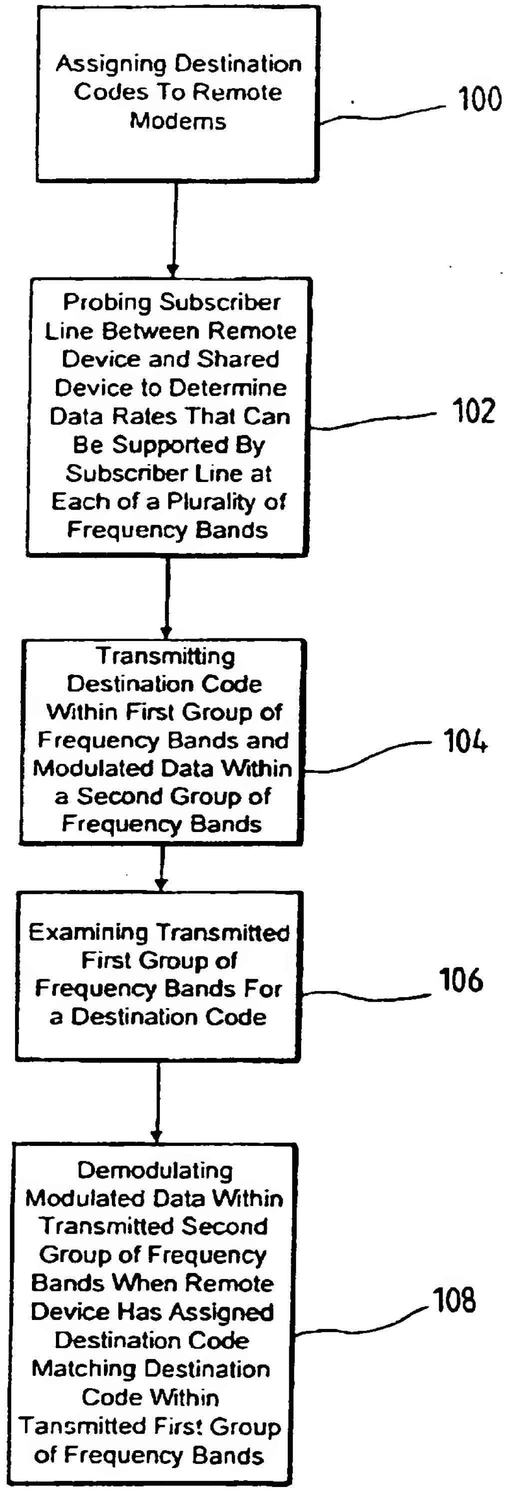

Assigning Destination Codes To Remote Modems
100
Probing Subscriber Line Between Remote Device and Shared Device to Determine Data Rates That Can Be Supported By Subscriber Line at Each of a Plurality of Frequency Bands
102
Transmitting Destination Code Within First Group of Frequency Bands and Modulated Data Within a Second Group of Frequency Bands
104
Examining Transmitted First Group of Frequency Bands For a Destination Code
106
Demodulating Modulated Data Within Transmitted Second Group of Frequency Bands When Remote Device Has Assigned Destination Code Matching Destination Code Within Tansmitted First Group of Frequency Bands
108

FIG. 5

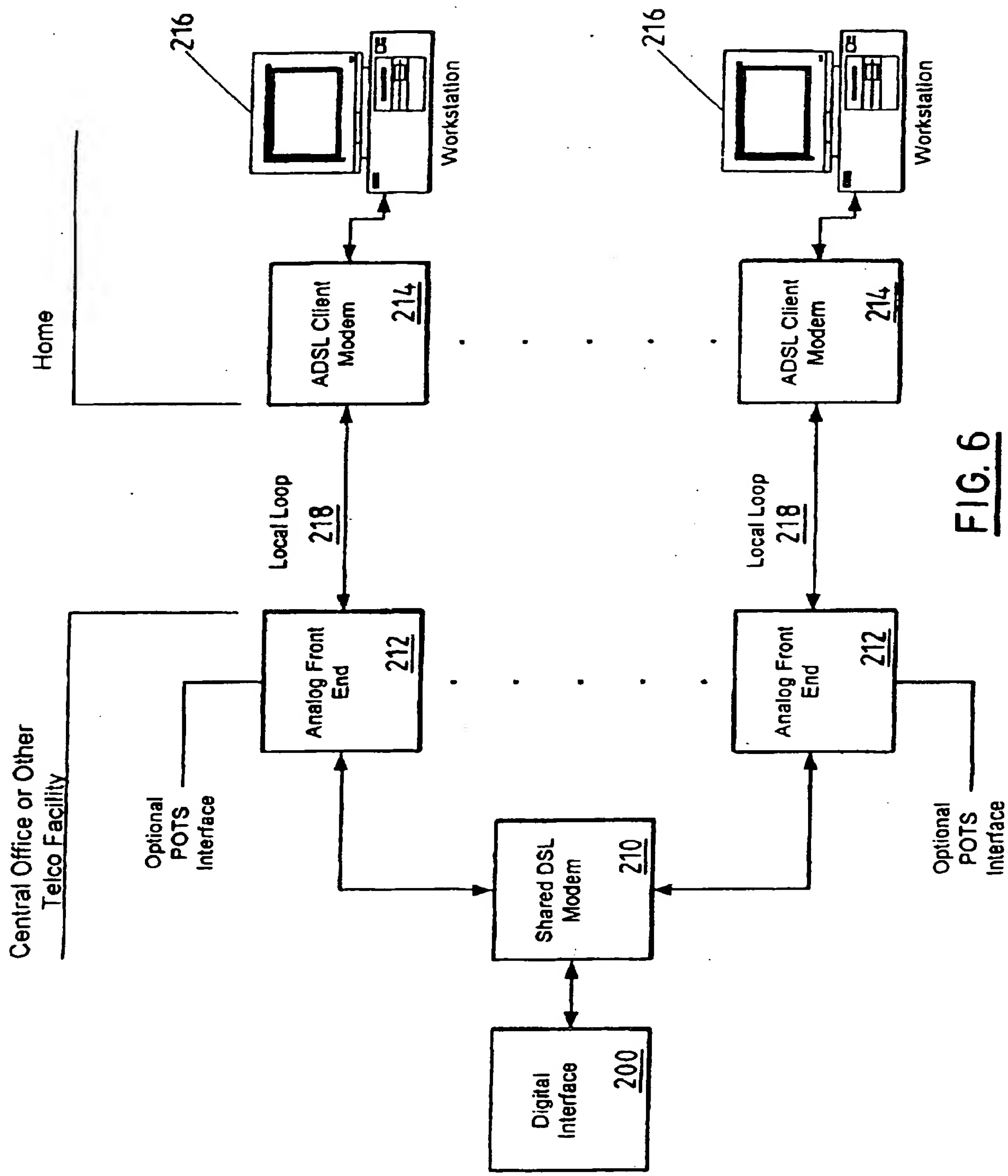
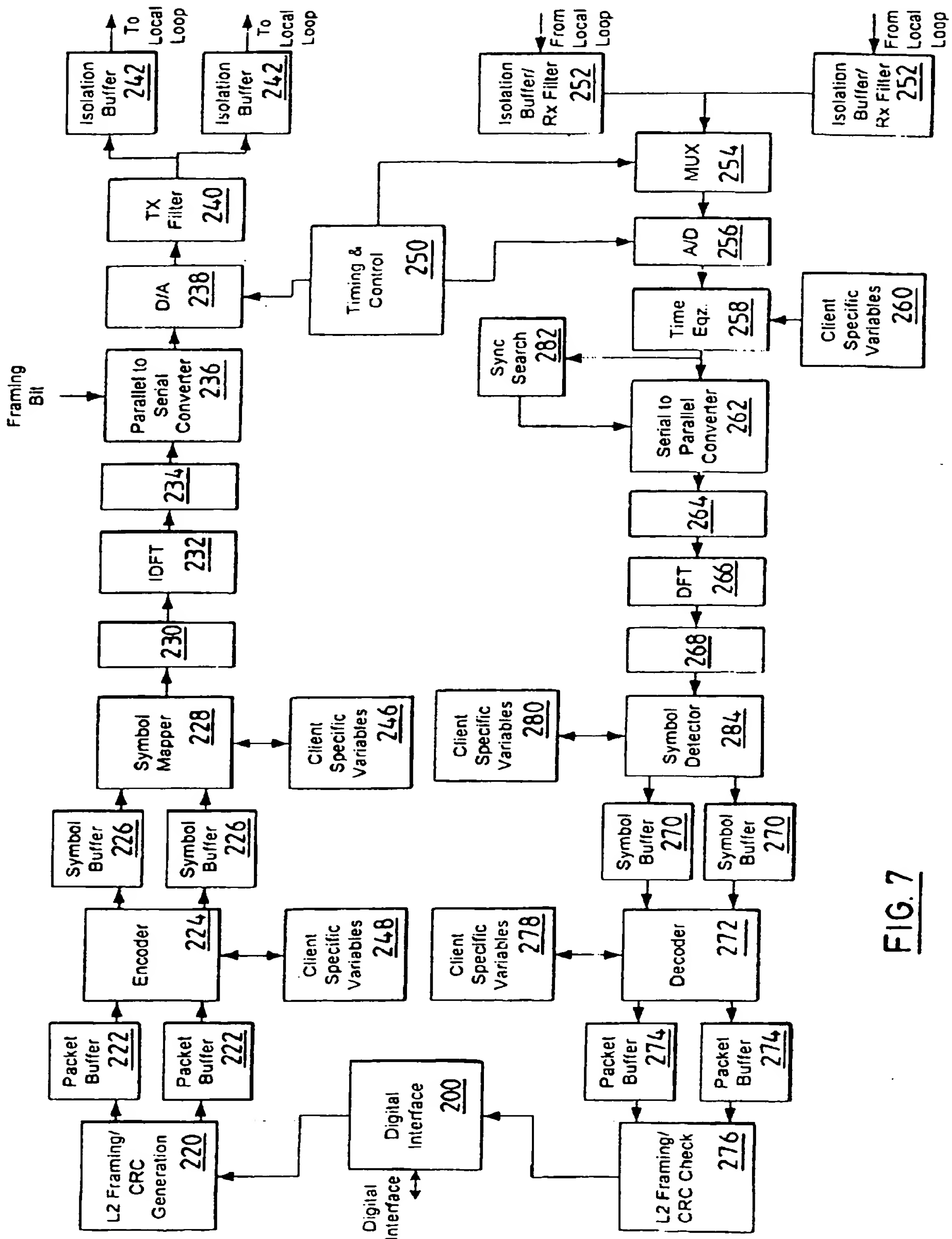

Central Office or Other Telco Facility
Home
Digital Interface 200
Shared DSL Modem 210
Optional POTS Interface
Analog Front End 212
Local Loop 218
ADSL Client Modem 214
Workstation
216
Analog Front End 212
Optional POTS Interface
Local Loop 218
ADSL Client Modem 214
Workstation
216

FIG. 6



Isolation Buffer 242
To Local Loop
Isolation Buffer 242
To Local Loop
Isolation Buffer/ Rx Filter 252
From Local Loop
Isolation Buffer/ Rx Filter 252
From Local Loop
TX Filter 240
MUX 254
A/D 256
D/A 238
Timing & Control 250
Time Eqz. 258
Client Specific Variables 260
Framing Bit
Parallel to Serial Converter 236
Sync Search 282
Serial to Parallel Converter 262
234
264
IDFT 232
DFT 266
230
268
Symbol Mapper 228
Client Specific Variables 246
Client Specific Variables 280
Symbol Detector 284
Symbol Buffer 226
Symbol Buffer 226
Symbol Buffer 270
Symbol Buffer 270
Encoder 224
Client Specific Variables 248
Client Specific Variables 278
Decoder 272
Packet Buffer 222
Packet Buffer 222
Packet Buffer 274
Packet Buffer 274
Digital Interface 200
L2 Framing/ CRC Generation 220
L2 Framing/ CRC Check 276
Digital Interface

FIG. 7

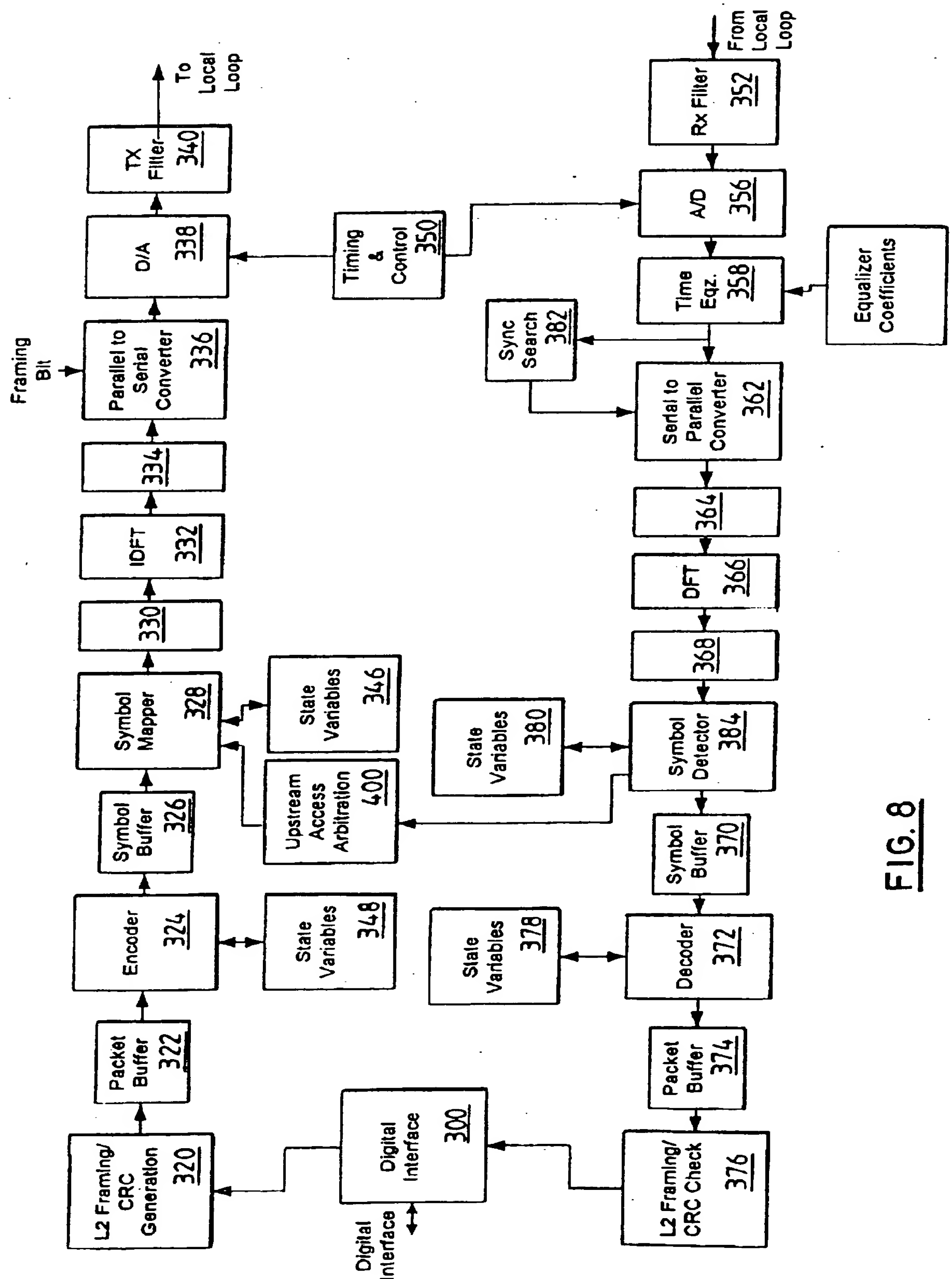

To Local Loop
TX Filter 340
D/A 338
Parallel to Serial Converter 336
Framing Bit
334
IDFT 332
330
Symbol Mapper 328
State Variables 346
Upstream Access Arbitration 400
Symbol Buffer 326
Encoder 324
State Variables 348
Packet Buffer 322
L2 Framing/ CRC Generation 320
Digital Interface 300
Digital Interface
Timing & Control 350
From Local Loop
Rx Filter 352
A/D 356
Time Eqz. 358
Equalizer Coefficients
Sync Search 382
Serial to Parallel Converter 362
364
DFT 366
368
Symbol Detector 384
State Variables 380
Symbol Buffer 370
Decoder 372
State Variables 378
Packet Buffer 374
L2 Framing/ CRC Check 376

FIG. 8